

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
28 February 2002 (28.02.2002)

PCT

(10) International Publication Number
WO 02/17518 A1

(51) International Patent Classification⁷: **H04B 10/17**

(21) International Application Number: PCT/US01/18996

(22) International Filing Date: 13 June 2001 (13.06.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/641,577 18 August 2000 (18.08.2000) US

(71) Applicant: CORNING INCORPORATED [US/US]; 1
Riverfront Plaza, Corning, NY 14831 (US).

(72) Inventors: EVANS, Alan F; 5090 County Route 41, 5090
County Route 41, Beaver Dams, NY 14812 (US). WILDE-
MAN, George; 54 Overbrook Drive, Painted Post, NY
14870 (US).

(74) Agent: SHORT, Svetlana Z; Corning Incorporated, SP TI
3 1, Corning, NY 14831 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ,
DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR,
HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR,
LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ,
NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM,
TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

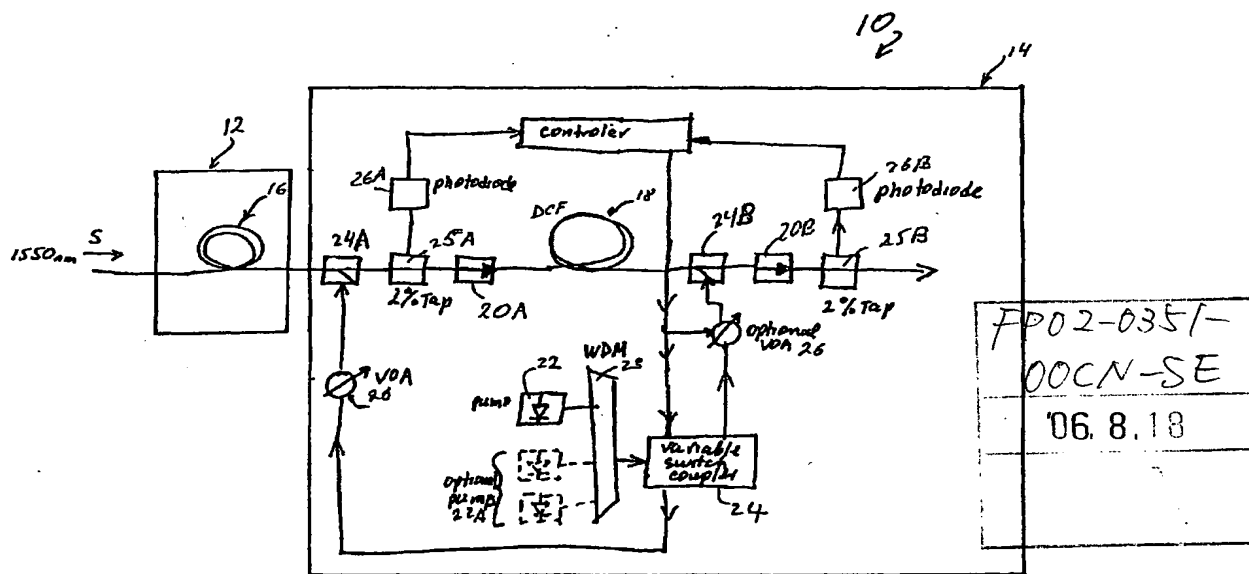
(84) Designated States (*regional*): European patent (AT, BE,
CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC,
NL, PT, SE, TR).

Published:

- with international search report
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments

For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.

(54) Title: AMPLIFIER SYSTEM WITH DISTRIBUTED AND DISCRETE RAMAN FIBER AMPLIFIERS



(57) Abstract: An amplifier system includes: a distributed Raman fiber amplifier and; a discrete Raman fiber amplifier that includes dispersion compensated fiber. The discrete Raman fiber amplifier is operatively connected to the distributed Raman fiber amplifier and amplifies signals received from the distributed Raman fiber amplifier. In one embodiment, at least one source of pump signal is coupled to the distributed and to the discrete Raman fiber amplifier. The distributed Raman fiber amplifier and the discrete Raman fiber amplifier in this embodiment share optical pump power provided by the shared pump.

AMPLIFIER SYSTEM WITH DISTRIBUTED AND DISCRETE RAMAN FIBER AMPLIFIERS

5

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 This invention relates to optical amplifier systems and more particularly, to systems including distributed and discrete Raman amplifiers.

2. Technical Background

15 Long distance communication systems typically use erbium doped fiber amplifiers between long spans of transmission fiber. A typical configuration for the erbium doped fiber amplifier includes one or more pump lasers operating at wavelengths of 980 nm or 1480 nm and providing an output coupled into the erbium doped fiber. Erbium doped fiber amplifiers (EDFAs) are discrete amplifiers. Such amplifiers are used to provide sufficient gain to compensate for loss of signal in transmission fiber, often requiring multiple high
20 power pumps. Erbium doped fiber amplifiers are used to produce high power out-going signal because, otherwise, as the signal travels through the transmission fiber, the attenuated signal level would approach the noise level by the time it reaches the next amplifier. Erbium doped fiber amplifiers typically have to be positioned at about one hundred kilometers or less from one another, otherwise the signal level would drop down to

approximately the noise level before reaching the next EDFA and the next amplifier might not be able to distinguish between the noise and the signal.

Discrete Raman fiber amplifiers can be used as amplifying devices that compensate for losses incurred by the signal during its transmission through the transmission fiber. For this purpose, the discrete Raman fiber amplifiers would also be situated between long lengths (typically 40-100 kilometers) of transmission fiber. Unfortunately, an amplifier system with only discrete Raman amplifiers suffers from MPI (multipass interference), from double Rayleigh backscattering, and gain saturation from the pump depletion.

Distributed Raman fiber amplifiers are sometimes used in conjunction with the Erbium doped fiber amplifiers. The typical distributed Raman fiber amplifiers utilize typical transmission fiber as the gain medium. However, the signal propagating through the distributed Raman amplifier undergoes distortion and, thus becomes broader due to chromatic effects produced by the fiber. This distorted signal is provided to and is amplified by the Erbium doped amplifier and, contributes to reduction of the signal to noise ratio. In order to compensate for the signal broadening, such an amplifier system typically utilizes a multistage Erbium doped fiber amplifier, which has a dispersion compensating fiber between the two amplifying stages of the Erbium-doped amplifier. Splicing a dispersion compensating fiber between two stages of the Erbium doped fiber amplifier introduces about 10 dB loss into the amplifier, which may be overcome by additional pumping power with a resulting increase in cost.

SUMMARY OF THE INVENTION

According to one aspect of the present invention an amplifier system includes: (i) a distributed Raman fiber amplifier and; (ii) a discrete Raman fiber amplifier that includes dispersion compensated fiber. The discrete Raman fiber amplifier is operatively connected to the distributed Raman fiber amplifier and amplifies signals received from the distributed Raman fiber amplifier. In one embodiment, at least one source of pump signal is coupled to the distributed and to the discrete Raman fiber amplifier. The distributed Raman fiber amplifier and the discrete Raman fiber amplifier in this embodiment share optical pump power provided by the shared pump. In one embodiment of the present invention an Erbium doped fiber amplifier (EDFA) is operatively connected to a discrete

Raman fiber amplifier and the Erbium doped fiber amplifier amplifies signals received from the discrete Raman fiber amplifier.

It is an advantage of the amplifier system of the present invention to have no or only minimal signal broadening without center stage a dispersion compensation fiber between EDFA stages. The loss, which would have been attributable to a dispersion amplifier, can instead be allocated to other components, such as Add/Drop multiplexer, polarization mode dispersion compensator, or dynamic gain equalization components.

It is another advantage of this invention that the optical amplifiers can be spaced at more than one hundred kilometers away from one another because the transmission losses are minimized due to use of distributed Raman fiber amplifiers.

For a more complete understanding of the invention, its objects and advantages refer to the following specification and to the accompanying drawings. Additional features and advantages of the invention are set forth in the detailed description, which follows.

It should be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various features and embodiments of the invention, and together with the description serve to explain the principles and operation of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates schematically a distributed Raman amplifier operatively connected to a discrete Raman amplifier that includes dispersion compensating fiber.

Figure 2 illustrates schematically an in-coming signal entering the distributed Raman amplifier of Fig. 1, a broadened out-going signal exiting this amplifier and a corrected signal exiting the discrete Raman amplifier of Fig. 1.

Figure 3 illustrates the gain profile of the amplifier system of Figure 1.

Figure 4 illustrates schematically a distributed Raman amplifier operatively connected to a discrete Raman amplifier, where the residual pump from the discrete Raman amplifier is shared within the distributed Raman amplifier.

Figure 5 illustrates the distributed Raman fiber amplifier operatively connected to a discrete Raman fiber amplifier, which is in turn operatively connected to an Erbium doped fiber amplifier.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. The first exemplary embodiment of the amplifier system of the present invention is shown in Figure 1, and is designated generally throughout by reference numeral 10. In accordance with the invention, the amplifier system 10 includes a distributed Raman fiber amplifier 12 and a discrete Raman fiber amplifier 14. The distributed Raman fiber amplifier 12 includes a length of transmission fiber 16 which is being Raman pumped by a counter propagating pump light. The effective length of the Raman pumped fiber 16 is between 40 km and 100 km, corresponding to the transmission span length. In a communication system the term "transmission span length" refers to the length of transmission fiber between two discrete amplifiers. Thus, the transmission fiber of the distributed Raman amplifier forms a "transmission span". Fiber 16 is, for example, a single mode fiber such as ITU standard designated fiber like G.652, G.653, or G.654. More specifically, fiber 16 may be SMF-28TM fiber, SMF-DSTM fiber, or LEAF^R fiber commercially available from Corning, Incorporated of Corning, NY. The signal propagating through this fiber 16 is amplified and, because of this, does not attenuate as rapidly as the signal propagating through a regular unpumped transmission fiber. The discrete Raman fiber amplifier 14 of this embodiment includes one or more coils of dispersion compensated fiber 18 as at least a part of the amplification (i.e. gain) medium of the discrete Raman fiber amplifier 14. Regular transmission fiber may also form a part of the amplification medium of the discrete Raman fiber amplifier. The dispersion compensation fiber 18 may be, for

example, Pure Mode™ DCF fiber, DCF- 40™ fiber, DCM -60™ fiber, or DCM - 80™ fiber, available from Corning, Incorporated. Utilizing the dispersion compensating fiber 18 as an amplifying medium enables the dispersion compensating fiber 18 to contribute to the amplification while it is compensating for the signal broadening.

More specifically, the discrete Raman fiber amplifier 14 is optically coupled and operatively connected to the distributed Raman fiber amplifier 12. The discrete Raman fiber amplifier 14 amplifies signals S' received from this distributed Raman fiber amplifier 12, providing a further amplified signal S". The out-going signal S' from the distributed Raman amplifier 12 are typically broadened (up to about 1/3 of a bit period relative to the in-coming signal S) due to chromatic dispersion effects introduced by the transmission fiber 16 of the distributed Raman amplifier 12. It an advantage of the present invention that discrete Raman fiber amplifier 14 utilizes the at least one coil of dispersion compensating fiber 18 to correct for this signal broadening, by providing dispersion compensation in, for example, the 1530 nm to 1570 nm signal band. This is shown schematically in Figure 2.

The dispersion compensating fiber 18 could be pumped just enough to make a loss-less broad band compensator. That is, the dispersion compensating fiber 18 can be pumped just enough to provide no gain or loss. A broad band is a wavelength band that is larger than 30 nm and is preferably 100 nm or even larger. In the amplifier system depicted in Figure 1 the dispersion compensating fiber 18 is pumped by a 200 mW pump to make the dispersion compensating fiber 18 a loss-less compensator. This pump provides optical pump signal in 1400 nm to 1500 nm range. If the dispersion compensating fiber 18 is provided with additional pump power, the discrete Raman fiber amplifier 14 will contribute net gain to the amplifier system 10.

In the illustrated embodiment, the discrete Raman fiber amplifier 14 also includes at least one isolator for preventing optical noise in the 1550 nm range from propagating in a direction counter to the signal direction. In this embodiment, the discrete Raman fiber amplifier 14 includes two isolators 20A and 20B with the gain fiber and/or the dispersion compensating fiber 18 in between. The first isolator 20A, on the upstream side of the fiber 18, prevents counter propagating noise signal from entering the distributed Raman fiber amplifier 12. The second isolator 20B, on the

downstream side of the fiber 18, prevents counter propagating noise signal from entering the dispersion compensating fiber 18.

In this embodiment, a 1450 nm pump 22 provides counter propagating pump light to both the DCF 18 and Distributed Raman fiber amplifier 12. It is preferred that the pump 22 provides counter (with respect to the direction of signal propagation) propagating pump energy, because such configuration reduces modulation of the optical signal produced by modulation of pump induced noise. However, co-directional pumping (i.e., pumping in the same direction as the signal being amplified) may be utilized if the noise of the pump is reduced (i.e. if the spectral coherence of the pump is increased). Additional pumps 22A may also be utilized to provide more pump power. These pumps 22, 22A may be coupled together, for example by a wave division multiplexer 23. More specifically, in this embodiment, the pump 22 may be a shared fiber Bragg grating stabilized Fabry Perot semiconductor laser diode pump. The pump light provided by the pump 22 enters a coupler 24 (for example, a tap beam splitter, a variable switch coupler or a 3dB coupler) which channels a smaller portion of the pump light toward a wavelength selective coupler 24B dedicated to the discrete Raman amplifier 14 and a greater portion of the pump light toward the wavelength selective coupler 24A dedicated to the distributed Raman amplifier 12. The amount of light provided by the pump 22 may be controlled, for example, via input and output 2% tap couplers 25A, 25B, photo diodes 26, and feedback circuit to the voltage-controlled switch coupler 24 and the variable optical attenuator VOA 26, to provide gain control for the distributed and discrete Raman amplifiers.

The gain profile of the above described amplifier system of Figure 1 is shown in Figure 3. As we can see, this amplifier system has a relatively flat gain curve even though the pump is being shared by the discrete Raman amplifier and the distributed Raman amplifier.

Figure 4 illustrates an amplifier system similar to the one depicted in Figure 1. However, the amplifier system illustrated in Figure 4 utilizes two coils of dispersion compensating fiber 18 and an optical component coupled therebetween. The amplifier system illustrated in Figure 4 also utilizes two sets of pumps 22A, 22B, one of which (22A) is being shared by the distributed Raman fiber amplifier 12 and the discrete Raman fiber amplifier 14. The other pump 22B supplies pump light to the distributed

Raman amplifier 12. This configuration conserves remnant pump power from the discrete Raman fiber amplifier 14 and applies it to the distributed Raman amplifier 12. This pumping configuration provides more pumping power to the amplifier system 10 and, therefore, results in more gain and more output power out of the amplifier system.

5 The distributed and the discrete Raman amplifiers may also share more optical pumps in a similar manner.

As embodied herein, and depicted in Figures 1 and 4, the wavelength selective couplers 24A and 24B may pass the signal light (typically centered at about the 1550 nm wavelength) in one direction and reflect pump light 1400 nm to 1500 nm in another

10 direction. Thus, the signal S' is routed by wavelength selective coupler 24A from the distributed Raman fiber amplifier 12 towards the discrete Raman fiber amplifier 14. The wavelength selective coupler 24A also routes a portion of the pump signal provided by the pump 22 towards the distributed Raman amplifier 12. Similarly, wavelength selective coupler 24B routes the signal S'' out of the amplifying medium

15 (dispersion compensating fiber 18, for example) of the discrete Raman fiber amplifier 14, while providing this amplifying medium with a counter propagating pump signal.

Another alternative embodiment of the amplifier system of the invention is shown in Figure 5. This amplifier system of Figure 5 is similar to the amplifier system 10 illustrated in Figure 1 in that it also utilizes the distributed Raman fiber amplifier 12

20 operatively connected to the discrete Raman fiber amplifier 14. However, in addition, this amplifier system also includes an Erbium doped fiber amplifier 30 optically coupled and operatively connected to the discrete Raman fiber amplifier 14. The Erbium doped fiber amplifier 30 may be, for example, a multistage amplifier with amplification stages 32A and 32B, an optional loss element 34 located therebetween

25 and a controller 35. The loss element 34 provides approximately 4dB to 12dB loss in the center stage of the Erbium doped fiber amplifier. Such loss elements may be, for example, add/drop multiplexers for wavelength switching or routing, gain flattening filters, polarization mode dispersion (PMD) compensators, or dynamic gain utilization devices.

30 Accordingly, it will be apparent to those skilled in the art that various modifications and adaptations can be made to the present invention without departing from the scope of the invention. It is intended that the present invention cover the modifications and

adaptations of this invention as defined by the appended claims and their equivalents.

What is claimed is:

1. An optical amplifier system comprising:
 - (i) a distributed Raman fiber amplifier and;
 - (ii) a discrete Raman fiber amplifier that includes a gain medium and a dispersion compensated fiber forming at least a part of said gain medium, said discrete Raman fiber amplifier being operatively connected and optically coupled to said distributed Raman fiber amplifier, whereby it will amplify signals received from said distributed Raman fiber amplifier.
2. The amplifier system according to claim 1, further comprising at least one source of pump signal coupled to said distributed Raman fiber amplifier and said discrete Raman fiber amplifier, whereby the distributed Raman fiber amplifier and the discrete Raman amplifier share the optical pump power provided by said pump.
3. The amplifier system according to claim 2, wherein said pump provides backward pumping for said distributed Raman fiber amplifier.
4. The amplifier system according to claim 3, wherein said pump, provides light in a 1400 nm to 1500 nm wavelength range.
5. The amplifier system according to claim 1, wherein said dispersion compensating fiber is a loss-less compensator.
6. The amplifier system according to claim 1, wherein said dispersion compensating fiber provides a net positive gain.

7. The amplifier system according to claim 1, further including an erbium doped fiber amplifier operatively connected to said discrete Raman fiber amplifier, said erbium doped fiber amplifier amplifying signals received from said discrete Raman fiber amplifier.

5

8. The amplifier system according to claim 1, a further comprising at least one isolator and at least one optical tap.

10

9. The amplifier system according to claim 1, wherein said discrete Raman fiber amplifier further comprises two optical isolators.

10. A method of amplifying an optical system comprising the steps of:

15

- (i) transmitting an optical signal through a distributed Raman fiber amplifier; and
- (ii) amplifying said optical signal by utilizing a discrete Raman amplifier that includes dispersion compensated fiber.

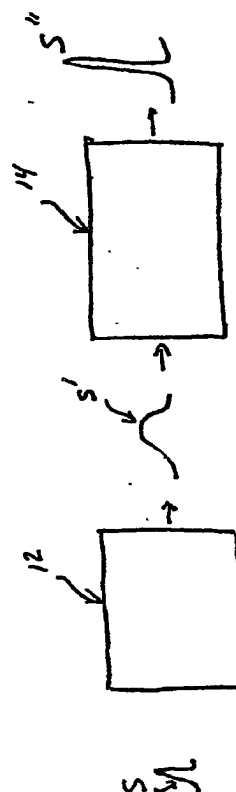
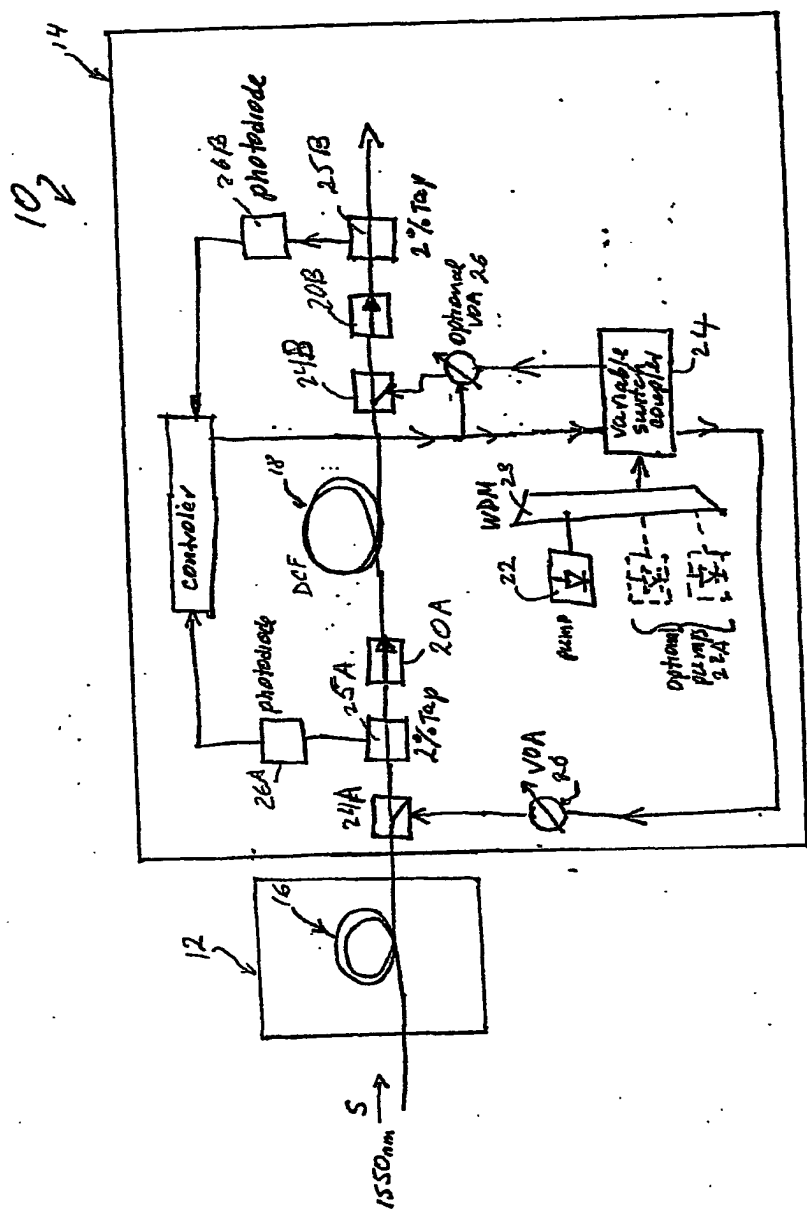
20

11. The method according to claim 10, further comprising the step of pumping said distributed to Raman amplifier and said discrete Raman amplifier with the shared optical pump.

25

12. The method of according to claim 10 further comprising the steps of:

- (i) providing an output signal from said discrete Raman fiber amplifier to an erbium doped fiber amplifier; and
- (ii) amplifying said provided output signal with said erbium doped fiber amplifier.



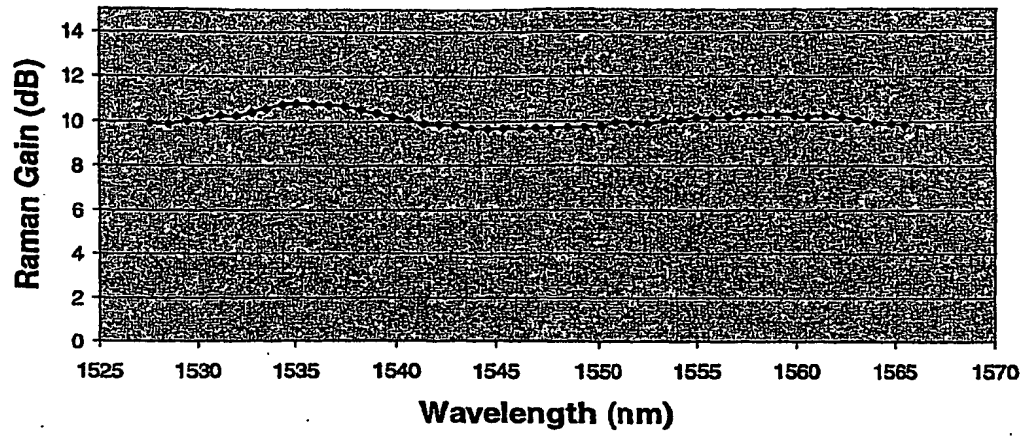


Figure 3

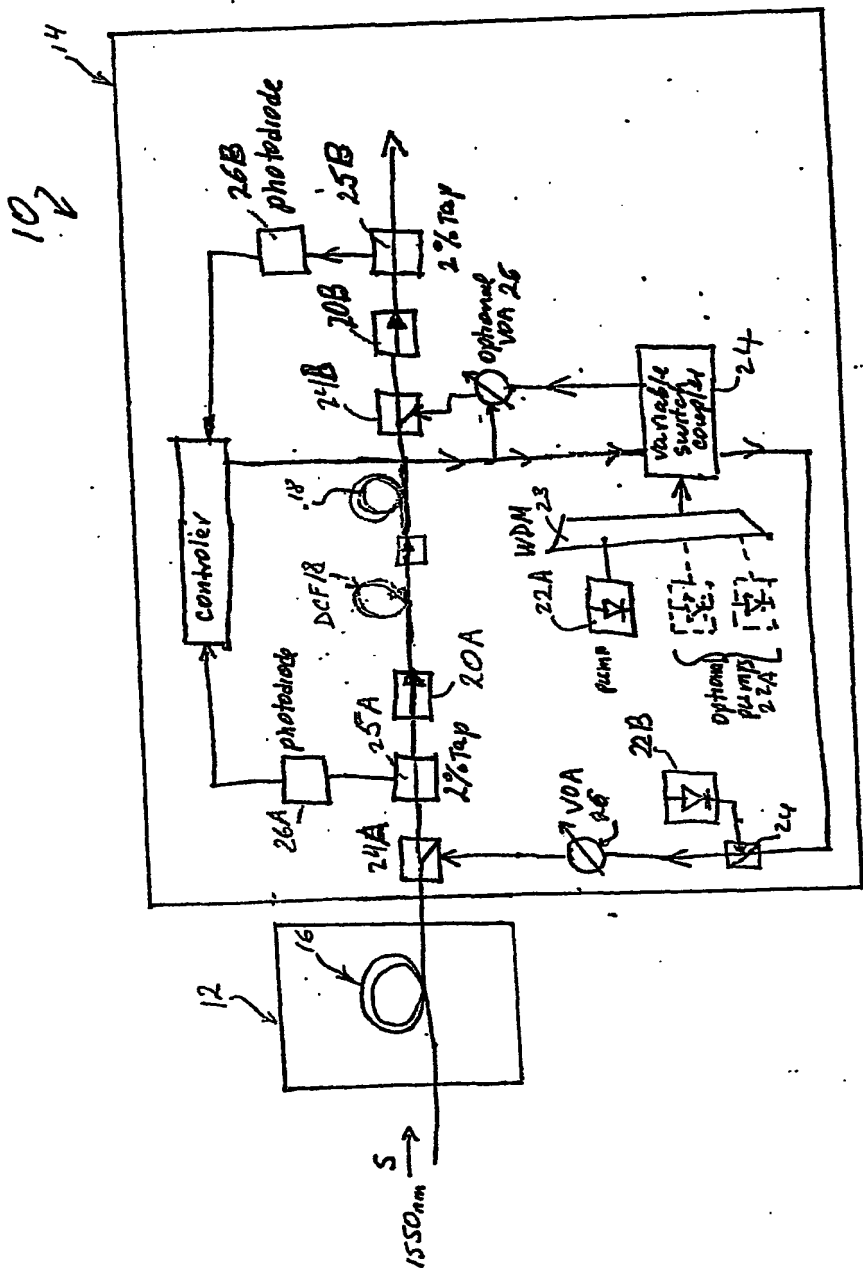


Fig 4

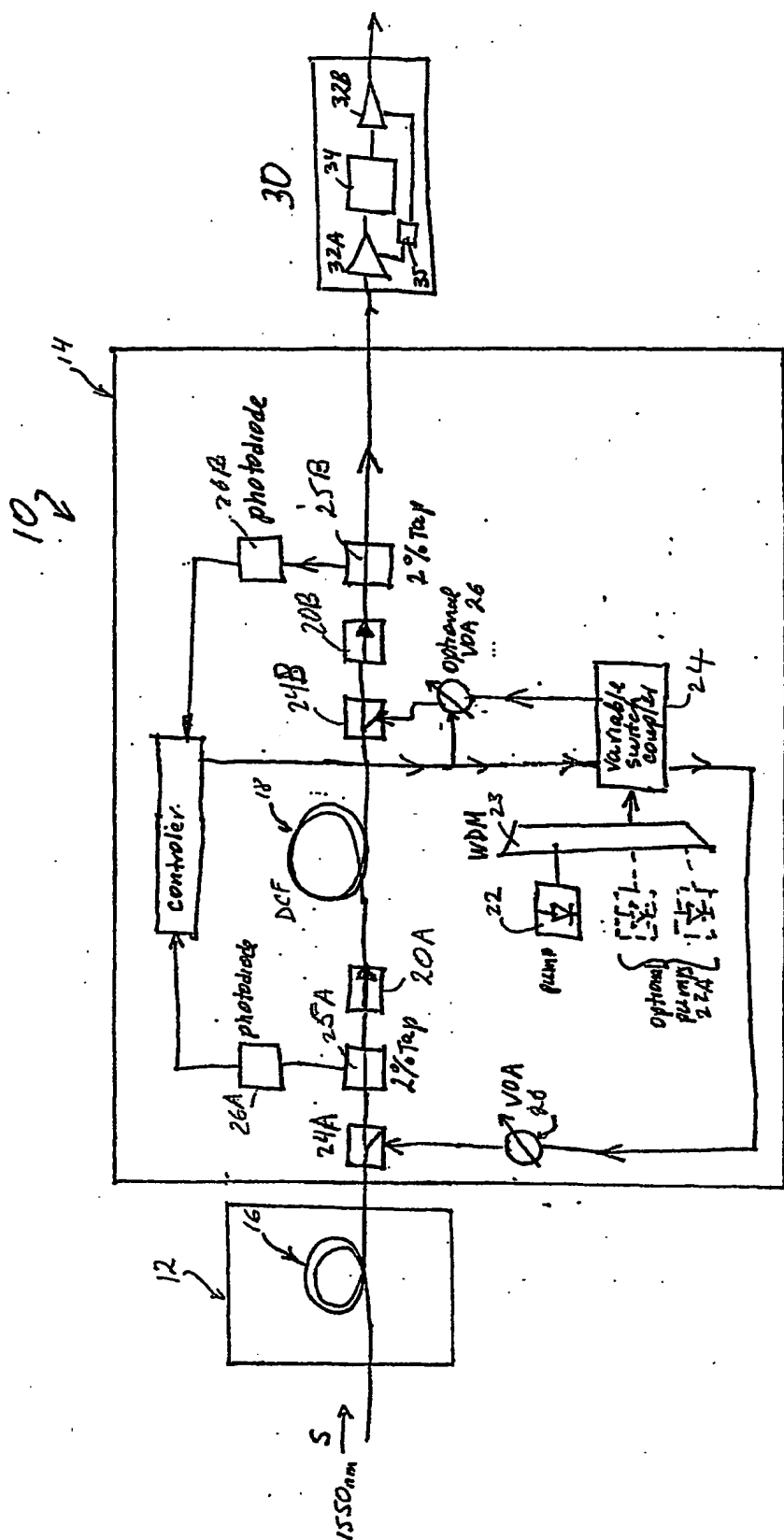


Fig. 5

INTERNATIONAL SEARCH REPORT

International ... ication No
PCT/US 01/18996

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04B10/17

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04B H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NAITO T: "ONE TERABIT/S TRANSMISSION OVER 10,000 KM USING C-BAND AND L-BAND" PROCEEDINGS OF THE EUROPEAN CONFERENCE ON NETWORKS AND OPTICAL COMMUNICATIONS 2000. NOC 2000. WDM AND PHOTONIC NETWORKS, PROCEEDINGS OF THE EUROPEAN CONFERENCE ON NETWORKS AND OPTICAL COMMUNICATIONS. NOC, AMSTERDAM: IOS PRESS, NL, vol. PRT 1 OF 2, 2000, pages 2-9, XP000993819 ISBN: 1-58603-068-X page 2, line 1 - line 10 page 4, line 1 - line 7 figure 3	1-12
A	WO 99 43107 A (CIENA CORP) 26 August 1999 (1999-08-26) page 4, line 19 -page 5, line 6	1-12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- * & * document member of the same patent family

Date of the actual completion of the international search

23 January 2002

Date of mailing of the international search report

29/01/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer:

Ribbe, A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/18996

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 9943107	A	26-08-1999	AU 3063299 A	06-09-1999
			EP 1036440 A1	20-09-2000
			WO 9943107 A1	26-08-1999
			US 6178038 B1	23-01-2001

THIS PAGE BLANK (USPTO)